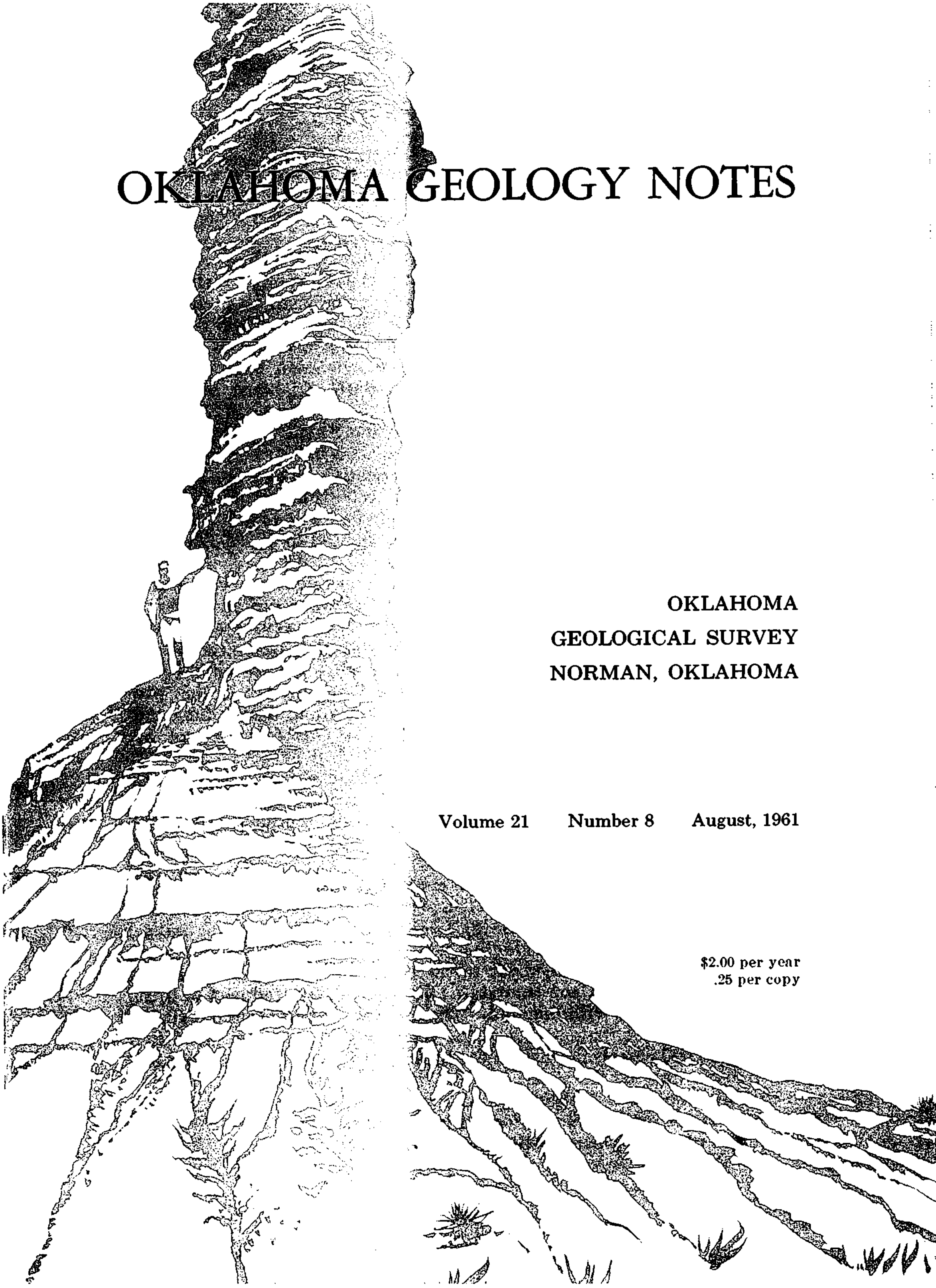

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1960 Statistics of Oklahoma's Petroleum Industry

Louise Jordan

The source for much of the statistics concerning the petroleum industry of Oklahoma, except where noted otherwise, is the annual review-forecast issue of the *Oil and Gas Journal* (vol. 59, no. 5, January 30, 1961).

Natural gas.—According to the U. S. Bureau of Mines, marketed production of natural gas from 65 counties in 1960 showed a slight decline in volume, but an 8-percent increase in value based on preliminary figures. Reserves continued to increase in the western counties, especially from Mississippian rocks in the Manning trend of Kingfisher, Garfield, and Major Counties. Deep Pennsylvanian gas discoveries scattered in the Arkoma basin of southeastern Oklahoma indicate a major gas province may be emerging.

Helium recovered from natural gas in the Keyes Gas Area of the Oklahoma Panhandle amounted to 277,427,000 cubic feet, valued at $4,505,000. The U. S. Bureau of Mines, operating its new helium plant which went on stream in August 1959, produced about 281 million cubic feet of helium, of which about 4 million cubic feet was added to storage. The amount of helium produced in 1959 amounted to 98,749,000 cubic feet, valued at $1,619,000.

Natural-gas liquids.—Recovery of natural-gas liquids in 68 natural-gasoline plants and 4 cycling plants reached a new record of 1,223 million gallons in 1960. Of this volume, the natural-gasoline and cycle-products components gained 10 percent and the LPG component gained 8 percent over 1959. The 72 plants have a total capacity of 2,955 million cubic feet of gas daily. Total natural-gas liquids produced daily amount to 4,089,418 gallons. Location, description, and products of the plants are listed in the *Oil and Gas Journal* (vol. 59, no. 12. Mar. 20, 1961, p. 115-116).

At present only four of the plants store their natural-gas products in underground caverns which have a total capacity of about 330,000 barrels. In 1961, Continental Oil Company will complete a 200,000-barrel cavern in the Wreford limestone (Permian) at a depth of 350 feet near Ponca City (S½ NW¼ and N½ SW¼ sec. 33, T. 25 N., R. 2 E.); and Warren Petroleum is currently washing out a cavern in salt beds immediately below the Cimarron anhydrite at their Mocane plant (SW¼ SE¼ NW¼ sec. 18, T. 5 N., R. 25 ECM).

Crude Petroleum.—Production of crude petroleum, an estimated 190 million barrels, declined for the second consecutive year as allowable production under the Interstate Oil Compact was reduced to bring it in closer balance with demand. The allowable production of 540,000 barrels per day at the opening of the year was adjusted downward to a low of 488,000 barrels per day in the third quarter, and averaged 513,000 barrels per day for the year.

The amount of footage drilled dropped 20 percent. The decline in number of exploratory holes drilled amounted to about 16 percent and that of development wells to 9 percent.

Table I.—Drilling Activity in Oklahoma, 1960

	1960						1959	1961
	CRUDE	CONDENSATE	GAS	DRY	SERVICE	TOTAL	TOTAL	FORECAST
All wells								
Number of completions	2,284	72	434	1,472	540	4,802[1]	5,359[2]	5,376
Footage	7,842,218	586,050	2,509,846	5,711,096	782,339	17,431,529	20,295,571	19,662,000
Average footage	3,477	8,140	5,783	3,879	1,449	3,630	3,787	
Exploration wells								
Number of completions	130	18	65	487		700	827	866
Percent of completions	18.6	2.6	9.3	69.5				
Footage	836,653	144,716	381,133	2,230,336		3,592,838	4,096,127	
Development wells								
Number of completions	2,154	54	369	985	540	4,102	4,532	4,510
Footage	7,005,565	441,334	2,128,713	3,480,760	782,339	13,838,691	16,199,444	

[1]Cable, 1,780; rotary 3,022
[2]Cable, 1,025; rotary 4,334. **Oil and Gas Journal,** January 30, 1961, p. 110 shows total 1959 completions as 6,230.

The search for oil and gas was focussed on the Manning trend covering about 400 square miles extending through Kingfisher County, where 21 exploratory holes out of 26 were productive, and 96 development holes out of 100 were successful.

The number of refineries in Oklahoma remains at 14, the same as at the end of 1959.

The number of stripper wells increased from 62,905 in 1958 to 68,836 at the end of 1959. Average production per well decreased from 3.76 to 3.63 barrels per day at the end of 1959.

Production from Oklahoma's 21 "Giant" fields (Allen, Avant, Bowlegs, Burbank, Cement, Cushing, Earlsboro, West Edmond, Elk City, Eola [Robberson consolidated Aug., 1959], Fitts, Glenn Pool, Golden Trend, Healdton, Hewitt, Little River, Oklahoma City, Seminole, Sho-Vel-Tum, St. Louis, and Tonkawa) amounted to 81,230,000 barrels or 42.9 percent of total annual production in 1960.

TABLE II.—HYDROCARBON PRODUCTION IN OKLAHOMA, 1959-1960

	1959	1960
Crude oil and lease condensate		
Total annual production (1,000 bbls)	196,487[2]	189,535[2]
Value ($1,000)	573,742[2]	553,442[2]
Cumulative production (1,000 bbls)	8,032,860[3]	8,222,395[2]
Daily production (bbls)	533,510	524,448
Total number of producing wells	79,867	80,409
Daily average per well (bbls)	6.9	6.5
Wells flowing naturally at end of year	2,987[4]	3,147[4]
Oil wells on artificial lift	78,128[4]	80,459[4]
Natural gas (MMCF)		
Total annual marketed production	811,508[1]	805,000[2]
Value ($1,000)	81,501[1]	88,500[2]
Total number of gas and gas-condensate producing wells	5,121[4]	5,875[4]
Natural-gas liquids (1,000 gals)		
Total annual marketed production	1,124,222[1]	1,223,100[2]
Value ($1,000)	56,513[1]	62,470[2]

[1]U. S. Bureau of Mines final.
[2]U. S. Bureau of Mines preliminary.
[3]Preliminary figure using 7,836,373,000 as cumulative production at end of 1958.
[4]**World Oil**, February 15, 1961.

Estimated remaining reserves in these "Giants" amounts to 845 million barrels or 38.9 percent of the total reserve. Oklahoma ranks fourth in the number of major fields, Texas first with 88, California second with 41, and Louisiana third with 34. These four states contain 77 percent of the remaining reserves of all fields. In the United States 53.6 percent of the remaining estimated reserves, 35,560 million barrels is in 235 "Giant" fields.

TABLE III.—ESTIMATED PROVED RESERVES IN OKLAHOMA*

	END OF 1958	END OF 1959	END OF 1960	CHANGE 1959-1960
Crude oil (1,000 bbls)	1,898,128	1,864,749	1,790,500	— 74,249
Natural-gas liquids (1,000 bbls)	357,507	367,569	338,313	— 29,256
Total liquid hydrocarbons (1,000 bbls)	2,255,635	2,232,318	2,128,813	—103,505
Natural gas (MMCF)	15,206,769	16,651,292	17,299,203	+647,911

*Reports of the American Petroleum Institute's Committee on Petroleum Reserves and Committee on Natural Gas Reserves of the American Gas Association; reprinted in part in **Oil and Gas Journal**, vol. 59, no. 13, Mar. 27, 1961, p. 64, 66, 67.

TABLE IV.—STRIPPER-WELLS IN OKLAHOMA, 1957-1959*

	END OF 1957	END OF 1958	END OF 1960
Number of stripper wells	59,983	62,905	68,836
Production (1,000 bbls)	92,102	86,273	91,329
Abandonments	831	476	1,331
Average daily production (bbls per well)	4.21	3.76	3.63
Producing acres	950,300	1,012,363	1,142,194
Reserves estimated at end of year (1,000 bbls)			
Primary	612,640	659,535	580,873
Secondary	704,740	724,130	661,371
Total	1,317,380	1,383,665	1,242,244

***Oil and Gas Journal** from surveys made jointly by Interstate Oil Compact Commission, National Stripper Well Association and Independent Petroleum Association of America: March 9, 1959, p. 87; May 23, 1960, p. 69; May 8, 1961, p. 70.

Bibliography and Index of Conodonts, 1949-1958
A Review

Robert O. Fay

A recent article by Sidney R. Ash, "Bibliography and index of conodonts, 1949-1958" (Micropaleontology, vol. 7, no. 2, p. 213-244, 1 text-fig., 1 table, April, 1961), is a bibliography and stratigraphic-geographic cross index, and bibliographic index of new names of species and higher categories, complete to December 31, 1958, beginning approximately at July 31, 1949. Approximately 1,100 articles have been published on conodonts from 1853 to 1958, at average rates of 4 per year until 1930, 20 per year until 1950, and 40 per year since 1950.

The bibliography includes 361 titles, of which 17 were published prior to 1949. Forty-two theses, completed from 1940 to 1958, are listed separately. A biennial supplement for 1959-1960, which will include articles omitted in the present paper, is in preparation.

The bibliographic index comprises only new names introduced, and includes those of 1 superfamily, 2 families, 38 genera, 3 subgenera, 418 species, 7 subspecies, and 16 varieties of disjunct units; and 3 genera and 3 species of assemblages.

The stratigraphic cross index by periods and formations (alphabetical) makes the work usable. In 1949, conodonts were known to range from Early Ordovican to Middle Triassic, and to occur in 16 countries. Since 1949, these boundaries have been extended from Late Cambrian to Late Triassic, in 31 countries.

Conodonts are recorded as occurring in Cambrian, Ordovician, Silurian, Devonian, and Mississippian rocks in Oklahoma:

Upper Cambrian
- Signal Mountain limestone (Branson, 1957a; Müller, 1956)

Middle Ordovician
- Bromide formation (Amsden, 1957a)
- Joins formation (Gatchell, 1948; Harris, 1957)
- McLish formation (Amsden, 1957a)
- Oil Creek formation (Amsden, 1957a)
- Simpson group (Amsden, 1957a)
- Tulip Creek formation (Amsden, 1957a; Harris, 1957)
- Viola limestone (Amsden, 1957a)

Silurian
- Chimneyhill formation (Amsden, 1957b)
- Clarita member of Chimneyhill formation (Amsden, 1957b)
- Cochrane member of Chimneyhill formation (Amsden, 1957b)
- Henryhouse formation (Amsden, 1957b)
- Hunton group (Echols, 1958)

Devonian
- Arkansas novaculite (Hass, 1951)
- Chattanooga shale (Hass, 1956; Huffman, et al., 1958; Lantz and Fitts, 1951)
- Woodford shale (Hass, 1958; Wilson, 1958)

Mississippian
- Arkansas novaculite (Hass, 1951)
- Caney shale (Hass, 1950)
- Delaware Creek member of Caney shale (Elias, 1956)
- Goddard shale (Elias, 1956)
- Sand Branch member of Caney shale (Elias, 1956)
- Stanley shale (Hass, 1950)
- Welden limestone (Peck, 1953)

Pennsylvanian (now considered Mississippian)
- Jackfork sandstone (Hass, 1950)
- Stanley shale (Hass, 1950)

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Correlation of Pre-Stanley Strata in the Arbuckle-Ouachita Mountain Regions*

William E. Ham

INTRODUCTION

The pre-Stanley rocks concerned with in this paper are of Devonian and older age. They include a sequence of Devonian, Silurian, and Ordovician strata with an exposed thickness of 3,800 to 6,300 feet in the Ouachita Mountains, and a sequence of Devonian, Silurian, Ordovician, and Upper Cambrian strata 6,800 to 11,500 feet thick in the Arbuckle Mountains.

The Ouachita Mountains have the form of a belt approximately 200 miles long, almost equally divided between Oklahoma and Arkansas, that extends from Little Rock westward to Atoka. About three-fourths of the pre-Stanley outcrops are in Arkansas, chiefly in a nearly continuous strip 100 miles long in the Mena-Mount Ida-Hot Springs-Little Rock area. The remaining one-fourth is in Oklahoma, chiefly in McCurtain County north of Broken Bow, in the Potato Hills area southwest of Talihina, and in Black Knob Ridge at Atoka. The outcrop areas are rather small but are widely distributed, giving a reasonable measure of geographic control and showing that the sequence thins westward while undergoing no appreciable change in facies in the 200-mile length of the Ouachita Mountain belt.

The sequence in the Ouachita Mountains extends from the top of the Arkansas novaculite down to the oldest exposed strata, Collier and Lukfata formations, here interpreted as of Early Ordovician age. The rocks are characterized by black shales, which predominate in the lower part of the sequence and are interbedded with other strata in the upper part. Fossils are sparsely distributed, graptolites and conodonts being the principal faunal elements. The rocks are only moderately well exposed, and structural complications are locally severe, so that stratigraphic relations and thicknesses are incompletely known.

The much smaller outcrops of the Arbuckle Mountain region cover about 900 square miles in a triangular area whose southeastern point lies barely 20 miles west of the Ouachita Mountains at Atoka. This is near the eastern edge of a broad region known as the "Arbuckle Mountain facies," which consists mostly of normal marine limestone, dolomite, sandstone, and shale, and extends generally westward and southward several hundred miles into Texas. The stratigraphic sequence includes all beds from the top of the Woodford formation to the base of the Reagan sandstone, and hence includes all strata of middle and early Paleozoic age down to the top of the Precambrian. Carbonate rocks predominate, and locally they contain abundant marine fossils such as brachiopods, trilobites, cephalopods, corals, and sponges. The term "Arbuckle facies" as used by geologists in the past refers to such car-

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*Reprinted with slight corrections and modifications from "The geology of the Ouachita Mountains—a symposium," Dallas Geological Society and Ardmore Geological Society, Amer. Assoc. Petroleum Geologists Field Trip, 1959.

bonate rocks and their accompanying green shales and quartzose sandstones. This facies is built up mostly of biochemical products in a carbonate rock environment, and as such it contrasts markedly with the black shales and predominant clastic rocks of equivalent age in the Ouachita Mountains.

It is the purpose of this paper to (a) establish with available control the correlation of all pre-Stanley stratigraphic units, primarily by a review of the literature, (b) discuss the contrasting geosynclinal aspects of the Arbuckle and Ouachita regions, (c) estimate probable depth to Precambrian rocks in McCurtain County, Oklahoma, and (d) show that maximum facies differences are restricted to rocks of the pre-Trenton Middle and Early Ordovician, and to the Silurian and Early Devonian, while intervening and closing stratigraphic units extend through both regions without appreciable change in thickness and with slight, but certainly non-discriminating, change in facies.

The conclusion is reached that although certain facies differences are indeed real, they are not yet sufficiently well established in space to compel acceptance of the concept of large-scale thrusting. Conversely, if a well is drilled in the frontal belt of the Ouachita Mountains and encounters black shale facies in the Womble and Mazarn formations, then the contrast between them and their nearby Simpson and Arbuckle equivalents will be so great that sole thrusting will have been established. A second approach, tried but not yet attained, would be the drilling of a well through the Ouachita rocks and finding beneath them a thick sequence of Arbuckle carbonates, or possibly Simpson green shales and bioclastic limestones interbedded with petroliferous quartzose sandstones.

In the preparation of this paper I have depended heavily on published accounts, but in addition I am indebted to William D. Pitt for furnishing composite stratigraphic sections of Ouachita rocks in McCurtain County, Oklahoma, and in southwestern Arkansas. Thomas W. Amsden kindly gave composite sections of Hunton strata in the Arbuckle Mountains and discussed with me the problems of correlating them with the Blaylock and Missouri Mountain formations. A new approach to correlating the Early Ordovician formations by graptolites and associated fossils was given to me by W. B. N. Berry in discussions during July, 1955. His familiarity with the graptolite faunas has made possible a more precise correlation of upper and middle Arbuckle limestones with black shales of the Womble and Mazarn formations.

STRATIGRAPHIC CLASSIFICATION

The stratigraphic successions in the Arbuckle and Ouachita Mountains are given in table I, and are summarized graphically in terms of principal facies in the cross section of figure 1. Arbuckle Mountain strata below the Sycamore have a maximum thickness of 11,500 feet on the southwest flank of the Arbuckle anticline, in the southwestern part of the outcrop region. Equivalent strata are 6,800 feet thick in the eastern part of the Arbuckle Mountains, the loss of section being mostly the result of thinning of individual formations in a less rapidly subsiding shelf environment rather than loss by erosion at unconformities.

Geosynclinal aspects are restricted entirely to rocks of Ordovician and Late Cambrian age, which are 10,800 feet thick in the west compared with 6,000 feet in the east, giving a west-east thickness ratio of nearly 2 to 1.

A direct comparison can not be made with the succession in the Ouachita Mountains because, as here interpreted, strata of Cambrian age are not exposed in that region. Pre-Stanley rocks of Ordovician (Early, Middle, and Late), Silurian, and Devonian age range in thickness from 6,300 feet in Arkansas to 3,800 feet in McCurtain County, Oklahoma. The westward loss in the thickness results from the wedge-out of Blakely sandstone as well as from marked thinning in the Mazarn, Womble, and Blaylock formations. This thinning trend westward toward the edge of the Ouachitas at Black Knob Ridge is confirmed by the complete absence of Blaylock sandstone (fig. 1), but can not be demonstrated for the Mazarn and Womble, as they are concealed or inadequately exposed.

In the Ouachita Mountains there are no Ordovician geosynclinal thicknesses to compare with those in the Arbuckle Mountains. Rather the pre-Stanley Ouachita rocks were deposited in a shallow offshore basin or shelf that was steadily being depressed from Early Ordovician through Late Devonian time. Both the rate of subsidence and the influx of clastic sediments were greater in the Arkansas part of the Ouachita Mountains, yielding a thicker section of sedimentary rocks than in the equivalent parts in Oklahoma, where the shelf was sinking more slowly and was receiving a greatly reduced volume of sandstone and shale.

CORRELATION

Devonian and older rocks in the two regions are dated and correlated by normal marine invertebrates and by conodonts. As shown in table I, conodonts have proved most valuable for the Devonian black shales, whereas graptolites in black shales of Ordovician and Silurian age from the Ouachita Mountains are most valuable for correlating with the richly fossiliferous limestones of the Arbuckle Mountains. Reasonable correlations can be made for all major stratigraphic units except (a) the Hunton limestone, whose probable equivalents in the Ouachitas are mostly unfossiliferous, and (b) the unfossiliferous basal few hundred feet below the Mazarn shale.

Woodford formation and Arkansas novaculite. The youngest rocks here considered are of Devonian and earliest Mississippian age. Through a study of conodonts Hass has shown that the middle division of the Arkansas novaculite of the Ouachita Mountains is essentially contemporaneous with the Woodford formation of the Arbuckle Mountains.

According to the interpretations of Hass (1951), based on the most exhaustive research yet done, the Arkansas novaculite at Caddo Gap, Arkansas, is 940 feet thick. The lower 785 feet or approximately 84 percent of the formation is of Devonian age, and the upper 155 feet or 16 percent is of Early Mississippian age. Most of the conodonts have been obtained from black shales in the middle division of the formation, which is 350 feet thick. The lower 320 feet of the middle division is of

TABLE I.--PRE-STANLEY CLASSIFICATION AND CORRELATION IN ARBUCKLE AND OUACHITA MOUNTAINS

System	Series	Group	Subgroup	ARBUCKLE MOUNTAINS	OUACHITA MOUNTAINS
Mississippian				Sycamore-Caney	Stanley
Devonian	Middle? and Upper			Woodford (C)	Arkansas novaculite: upper div. (U) middle div. (C) lower div.-Pinetop chert (U)
Devonian	Lower	Hunton group		Frisco (Oriskanian) (M) Haragan-Bois d'Arc (Helderbergian) (M)	Absent?
Silurian	Lower Middle Upper	Hunton group		Henryhouse (M) ------?------	Missouri Mountain (U)
Silurian	Lower Middle Upper	Hunton group		Chimneyhill (M) ------?------	Blaylock (G)
Ordovician	Upper			Sylvan (G)	Polk Creek (G)
Ordovician	Upper			Fernvale (M)	Bigfork (GM)
Ordovician	Middle			Viola (MG)	
Ordovician	Middle	Simpson group		Bromide (M) Tulip Creek (M) McLish (M) Oil Creek (M) Joins (M)	Womble (G)
Ordovician	Lower	Arbuckle group	Upper	West Spring Creek (MG)	Blakely (G)
Ordovician	Lower	Arbuckle group	Upper	Kindblade (M)	Mazarn (G)
Ordovician	Lower	Arbuckle group	Middle	Cool Creek (M)	Crystal Mountain (U) Collier (U) Lukfata (U)
Ordovician	Lower	Arbuckle group	Middle	McKenzie Hill (M) ------?------	
Cambrian	Upper	Arbuckle group	Lower	Butterly (M) Signal Mountain (M) Royer (U) Fort Sill (M)	not exposed
Cambrian	Upper	Timbered Hills group		Honey Creek (M) Reagan (U)	
Precambrian				granite and rhyolite	not exposed

(M) typical marine fauna (G) graptolites (C) conodonts (U) unfossiliferous or virtually so

Late Devonian age, whereas the upper 30 feet is of Early Mississippian (Kinderhookian) age. The lower division is 465 feet thick and consists of unfossiliferous massive novaculite or chert; it is believed by Hass to be of Onondagan (early Middle Devonian) age. The upper division of the novaculite is 125 feet thick at Caddo Gap and likewise is sparingly fossiliferous, yet Hass cites good evidence for believing it to be late Kinderhookian or Osagean.

Hass (1956, p. 27-29) also has shown that the four conodont zones which characterize the middle division of the Arkansas novaculite are represented in the Woodford formation, indicating their age equivalence. The lower three of these are of Upper Devonian age, and each has been found in the Woodford at several localities in the Arbuckle Mountains.

The top conodont zone is Early Mississippian, and equivalents of this zone have been found in the top foot or two of the Woodford on Henryhouse Creek and near Ada, in the Arbuckle region. The Woodford formation in most parts of the Arbuckle Mountains is 300-400 feet thick and is entirely similar lithologically to the middle division of the Arkansas novaculite, as it consists of black shale, siliceous shale, and beds of chert.

The Arkansas novaculite extends from Arkansas into McCurtain County and into the frontal belt of the Ouachita Mountains, changing westward in thickness and locally in character. In Black Knob Ridge the formation is 360 feet thick (Hendricks, et al., 1937, p. 25). The lower 130 feet is massive and thin-bedded gray chert or novaculite considered to be the lower division of the formation. The upper 230 feet is shale and novaculite of the middle division, considered to be equivalent to the Woodford formation. The upper division, prominent in Arkansas, is not recognized. From the exposures in Black Knob Ridge it is clear that both the lower and middle divisions of the novaculite are thinner at the western margin of the Ouachita Mountains, having in general less than half their thickness at Caddo Gap, Arkansas. Such westward thinning also characterizes the pre-novaculite formations.

There is no major discontinuity between the Arkansas novaculite and the Woodford formation, either in terms of age or lithology, and the two formations are here considered to have been deposited as a blanket extending continuously within and between the Ouachita and Arbuckle Mountains, as well as extending northward and westward as a black shale facies over many hundred thousand square miles.

The principal unsolved problem concerns the lower division of the Arkansas novaculite and its equivalents, if any, in the Woodford formation. This unit in the Ouachita Mountains is almost wholly unfossiliferous. The nearest approach to an answer may be found in the Pinetop chert of Hendricks (1947, sheet 1), which crops out in a ridge in secs. 3 and 4, T. 2 N., R. 15 E. It contains some sparsely fossiliferous limestone beds and lenses, and is correlated with the lower division of the novaculite. T. W. Amsden (personal communication) has found post-Hunton carbonate rocks of somewhat similar character locally in the Arbuckle Mountains, and pending further faunal studies he has indicated a possible correlation between them and the Pinetop chert.

Devonian strata of the Hunton group. Approximately the upper half of the Hunton group in the Arbuckle Mountains is of Devonian age. Through the early studies of Reeds (1911) and the more recent and much more comprehensive studies by Amsden, a sequence of fossiliferous limestones and marlstones locally 400 feet thick has been shown to be of Early Devonian age. According to Amsden (1957, 1958a, 1958b) the Haragan and Bois d'Arc formations are Helderbergian, whereas the Frisco formation at the top of the Hunton group is Deerparkian, close in age to the Oriskany sandstone.

This sequence has no lithologic counterpart in the Ouachita Mountains. If the lower division of the Arkansas novaculite is of Onondagan age as suggested by Hass, it is possible that Oriskanian and Helderbergian strata are absent, even in Arkansas where the stratigraphic succession is thickest.

Until better paleontologic control is available, possibly from studies of spores and pollen, little can be said about Early Devonian rocks in the Ouachitas. An unconformity at the base of the novaculite, corresponding to the well-known unconformity at the base of the Woodford, may have resulted in local removal of older beds. Reliable evidence for such an unconformity is not known in the Ouachita Mountains, however, and it seems more likely that Early Devonian strata are represented, either in the siliceous sediments low in the Arkansas novaculite or in the variegated shales of the Missouri Mountain formation. Although generally considered Silurian on the basis of stratigraphic position and a few poorly preserved fossils (Hendricks, 1947, sheet 1), the Missouri Mountain is not yet accurately dated; and the unconformity at its base, which in Black Knob Ridge results in removal of the Polk Creek shale (Hendricks, 1947, sheet 1), may mark the beginning of Devonian time.

Henryhouse-Chimneyhill and Missouri Mountain-Blaylock. Limestones and marlstones of undoubted Silurian age make up the lower part of the Hunton group in the Arbuckle Mountains. They have a composite thickness of approximately 350 feet, but owing to erosion beneath several unconformities within the group this composite thickness is nowhere attained at one locality. Locally all Silurian strata are absent, and in two areas they are built up to a maximum thickness of about 300 feet. The Chimneyhill and Henryhouse formations that make up this sequence are at some places richly fossiliferous, and according to Amsden (1957) they are probably of Early (Alexandrian), Middle (Niagaran), and early Late Silurian age.

Silurian faunas in the Arbuckle Mountains include probably at least a hundred species of brachiopods, trilobites, corals, sponges, Bryozoa, cephalopods, gastropods, graptolites, and pelecypods. These faunas are unknown in the Ouachita Mountains, where presumably equivalent beds are composed of sandstone interbedded with black and yellowish-gray shale of the Blaylock formation.

In Oklahoma the Blaylock sandstone is present only in McCurtain County, where it is 800-900 feet thick and consists of fine-grained chloritic quartzite interbedded with black, blue, and gray shale (Honess, 1923, pp. 87-99; Pitt, 1958, personal communication). A few worm trails cover some of the lower sandstone beds, but otherwise the formation is unfossiliferous. No Blaylock sandstone occurs in the frontal belt of the Ouachita Mountains, and it is clear that the formation disappears northward and westward both in Oklahoma and in Arkansas.

The Blaylock reaches its maximum thickness of 1,500 feet in the southern part of the Ouachita Mountains in Arkansas, and in that area it consists of angular fine-grained quartz and feldspar in sandstone layers interbedded with black and gray shale (Miser and Purdue, 1929, pp. 42-44). The only fossils useful for dating the Blaylock are graptolites found in shale in the lower part of the formation at one locality on Blaylock Mountain. From the collection made there by Miser, Ulrich identified seven species of graptolites, in the genera *Monograptus, Dimorphograptus, Gladiograptus,* and *Dictyonema,* by which he made a correlation with the Birkhill shales of Scotland, considered in Great Britain to be the base of the Silurian system (Miser and Purdue, 1929, p. 45). The Birkhill graptolite fauna is otherwise unknown in America.

Because most of the Blaylock formation is unfossiliferous, there remains a great question as to its equivalents in the Hunton group. Where present in maximum development there is no direct evidence for unconformity within the Blaylock, and presumably it is wholly of Silurian age, equivalent to the Chimneyhill and perhaps to the Henryhouse.

Overlying the Blaylock is the Missouri Mountain formation, which is everywhere present at its expected stratigraphic position in the Ouachita Mountains. In distribution it is similar to the Arkansas novaculite, as both of them are widespread blanket deposits that cover extensive tracts. They are completely unlike the previously deposited Blaylock sandstone, whose occurrence depends mostly on rate of basin sinking and the supply of clastic sediments from a southeastern source.

The Missouri Mountain formation ranges in thickness and character as follows: 50 to 300 feet of black, red, and green slates or shales in Arkansas (Miser and Purdue, 1929, pp. 45-49); 60 to 100 feet of black and gray slaty shale interbedded with thin greenish-gray sandstone in McCurtain County, Okla. (Honess, 1923, pp. 104-109); and 110 feet of green siliceous shale and interbedded chert in the Black Knob Ridge area (Hendricks, 1947, sheet 1). All strata are unfossiliferous except "a few conodonts, spicules, and fragments of brachiopods . . . , together with one bryozoan" from the upper part of the formation at Black Knob Ridge (Hendricks, 1947). The Missouri Mountain clastic sediments thus contain some faunal elements, but so far there is insufficient evidence to establish a reliable age. Possibly the variegated shales are equivalent in part to the silty and shaly limestone of the Henryhouse, and possibly they are younger than Silurian.

Regardless of the lack of accurate correlations, it is clear that the calcareous fossiliferous rocks low in the Hunton group are not faunally or lithologically represented in the Ouachita Mountains, and that contrasting lithologies and sedimentary environments characterize the Arbuckle and Ouachita provinces during Silurian time.

Sylvan-Polk Creek. In Arkansas and in McCurtain County, Oklahoma, the Polk Creek is mostly black shale or slate approximately 100 feet thick. It is described as ". . . coal-black, graphitic, firmly indurated but soft slate and shale . . ." by Honess (1923, p. 81), and ". . . black, fissile, and carbonaceous . . ." by Miser and Purdue (1929, p. 40). Where present in Black Knob Ridge, i.e., not removed by pre-Missouri Mountain erosion, it is at least 139 feet thick and consists of hard black paper shale that grades upward into soft brown platy shale (Hendricks, 1947, sheet 1).

In the Arbuckle province, the corresponding Sylvan shale is mostly 150 to 300 feet thick, thickening progressively westward, and consists of grayish-green shale that is calcareous in the lower part. In addition to a well-known fauna of graptolites, Wilson (1958) has recently discovered chitinozoans and hystrichosphaerids in this formation.

If all the stratigraphic units of the Arbuckle and Ouachita Mountains were as distinctive and as certainly correlatable as the Sylvan and Polk Creek formations, the only problems remaining would be those of structural interpretation. Both the black shales and slates of the Polk Creek and the green shales of the Sylvan have yielded an Upper Ordovician graptolite fauna that establishes the two formations as equivalents. When Decker published his comprehensive report describing nine species in five genera, including the guide fossil *Dicellograptus complanatus,* he cautiously wrote ". . . as nearly all graptolites of the Sylvan shale have been found in the Polk Creek shale of Arkansas, the practical equivalence of large parts of these formations seems to be established . . ." (Decker, 1935, p. 699). Thus from their contemporaneity and the knowledge that the same general range of thickness is shown for each formation in each province, it is perfectly clear that during Late Ordovician time a single deposit of shale extended uninterruptedly across southern Oklahoma and Arkansas, changing westward from black to green. Substantially the same deposit extends even farther northward as the Sylvan shale in northeastern Oklahoma (Huffman, 1953; Decker and Huffman, 1953), the Cason shale of northern Arkansas, and the Maquoketa shale of Iowa, Missouri, Illinois, Minnesota, and Wisconsin. The Polk Creek-Sylvan-Cason-Maquoketa sequence is almost as widely distributed as the black shales in the Arkansas novaculite, Woodford, Chattanooga, New Albany, Antrim, and Ohio shale. For each of these periods of time, uniform environmental conditions and a slow steady rate of subsidence characterized regions nearly continental in extent. Against this background it is hardly conceivable that the Arbuckle and Ouachita provinces occupied separate basins during the Late Ordovician and Late Devonian—certainly during these epochs there was no barrier between them.

Viola-Bigfork. That the Viola limestone of the Arbuckle Mountains is equivalent to most or all of the Bigfork chert in the Ouachita Mountains is now better established than the early works of Decker (1936a, 1936b) would indicate. Of the more recent workers both Hendricks and Harlton correlate these units unquestionably. In Black Knob Ridge, according to Hendricks (1947, sheet 1) "The fauna of the Bigfork is composed of graptolites, small brachiopods, trilobites, conodonts, spicules of various sorts, and small bodies which may be radiolarians. The graptolites occur at several horizons throughout the formation, and for the most part they are conspecific with those found in the Viola limestone of the Arbuckle region." An even clearer concept is given by Harlton (1953, p. 785), who wrote: "The fauna of the Bigfork chert at Black Knob Ridge is decisively conspecific with that found in the Viola limestone of the Arbuckle region. The fauna consists of trilobites, brachiopods, conodonts, and abundant graptolites. From a faunistic viewpoint it is clear that the chronological ages of the Bigfork and the Viola are identical. It can logically be held that these deposits are synchronous and their origin was in the same sea."

The fossils indicate a Middle Ordovician (Trenton) age in the Arbuckle Mountains and at Black Knob Ridge, and Ulrich likewise gave a Trenton age from graptolites in the Bigfork in Arkansas (Miser and Purdue, 1929, pp. 38-39). Decker (1936a, 1936b) has correlated the lower part of the Viola with the upper parts of the Womble in Arkansas and the Stringtown shale (now called Womble) at Black Knob Ridge, but the more recently expressed views of Hendricks and Harlton are probably correct and are accepted by the present writer.

The Viola-Bigfork stratigraphic unit is a valuable datum, ranging in thickness from 400 to 800 feet over thousands of square miles, and changing but slightly in lithology from black and gray chert and cherty limestone in the core area of the Ouachita province, to gray chert and limestone at Black Knob Ridge, and to gray limestone containing disseminated silica and nodules of chert in the Arbuckle province. The statement of Harlton that the two formations are deposits in the same sea is fully acceptable. The only notable change in lithology, other than the westward loss in percentage of silica, is the westward disappearance of black chert and black shale interbeds.

Both in Arkansas and in McCurtain County, Oklahoma, the Bigfork formation is about 600-700 feet thick, as near as can be estimated, and consists of coal-black chert and gray to black limestone or cherty limestone, together with thin interbedded layers of black siliceous and carbonaceous shale (Miser and Purdue, 1929, pp. 36-37; Honess, 1923, pp. 70-79). In the detailed section measured by Honess (1923, pp. 74-79), 287 feet of the Bigfork is so well exposed that a bed-by-bed description is given, and of this thickness 90 feet or approximately one-third of the exposed sequence is limestone or cherty limestone.

In Black Knob Ridge the formation is consistently about 600 feet thick. A section measured at Grant's Gap shows that gray bedded chert and limestone or cherty limestone constitutes approximately the lower 400 feet, in a ratio of about 80 percent chert to 20 percent limestone, and that nearly 200 feet at the top is composed of black and dark brown laminated chert containing interbedded black shale (Hendricks, Knechtel, and Bridge, 1937, p. 23).

The corresponding Viola limestone ranges in thickness from 400 feet in the eastern part of the Arbuckle Mountain region to 800 feet in the southwestern part. Wengerd (1948) has published a detailed account of this formation, showing that (1) it thickens regularly toward the southwest, and (2) the percentage of insoluble residue, which is mostly chert, disseminated silica, and quartz sand grains, changes from 5-10 percent in the east to about 15 percent in the west. Fine- and medium-grained limestone, much of it richly fossiliferous, makes up most of the formation. The basal 50 to 100 feet of the Viola in most of the outcrop sections is composed of laminated limestone containing approximately 25 percent disseminated silica. It weathers by leaching of carbonate minerals to a highly porous tripoli rock. This distinctive unit contains numerous graptolites and specimens of the lace-collar trilobite *Cryptolithoides*. It rests with abrupt contact on fine-grained limestone of the Bromide formation, which contains no chert or disseminated silica, practically no graptolites, and no *Cryptolithoides*. All these relations indicate that an unconformity of some magnitude is present between the Viola and Bromide formations.

The Fernvale limestone, presumably of Late Ordovician age, lies above the Viola limestone and below the Sylvan shale in the Arbuckle Mountains. It has a maximum thickness of about 65 feet at Lawrence, where the coarse-grained limestone is well exposed in quarries of the

Ideal Cement Company. The beds contain a wealth of fossils, chiefly brachiopods and trilobites. This fauna has not been investigated thoroughly, and correlation of the Fernvale into the Ouachita sequence has not been demonstrated. As no coarsely crystalline bioclastic limestone of the Fernvale type is present between the Bigfork and Polk Creek formations, the Fernvale horizon is either absent or is represented by a completely different lithology.

Simpson-upper Womble. The major contrasts in facies between the Arbuckle province and the Ouachita province are in rocks of pre-Trenton age. In the Arbuckles most pre-Viola strata are limestones and dolomites, together with some green shales and sandstones, whereas in the Ouachitas most pre-Bigfork strata are black shales and sandstones, together with a poor representation of carbonate rocks. A fair measure of paleontologic control is available for correlating between the two provinces, but much remains to be learned. It is unfortunate that exposures in the Ouachita Mountains are not geographically better distributed, for aside from short sections of the Womble shale in Black Knob Ridge and the Potato Hills, there are no outcrops of pre-Trenton beds closer to the Arbuckle Mountains than central McCurtain County, an airline distance of 100 miles.

In the Ouachita Mountains the Womble shale underlies the Bigfork chert, apparently with a conformable contact, and overlies the Blakely sandstone, or the Mazarn shale where the Blakely is absent. The Womble in Arkansas is mainly black shale about 1,000 feet thick, containing thin sandstone beds throughout and, in the upper part, some beds of black chert as well as sporadic lenses of black limestone (Miser and Purdue, 1929, p. 32). Thirty-three species of graptolites from excellent exposures of the formation at Crystal Springs, Arkansas, were identified by Ulrich and assigned a Normanskill or Late Chazyan age (Miser and Purdue, 1929, pp. 34-35). This fauna has been found at several stratigraphic positions of the Womble in Arkansas, indicating that much of it, probably all but the basal part, is Middle Ordovician.

No fossils have been found in corresponding beds of McCurtain County, Oklahoma, where strata above the Mazarn and below the Bigfork are called Womble and are estimated to be about 600 feet thick (Pitt, 1958, personal communication). Most of the formation consists of poorly exposed black fissile shale and siltstone, but the basal 66 feet is well exposed and is built up of limestone and silty limestone interbedded with black shale and siltstone (Pitt, 1955, pp. 24-25).

The upper 260 feet of the Womble is exposed in Black Knob Ridge. It consists of an upper unit of black and brown partly cherty shale 80-95 feet thick, and a lower unit with an exposed thickness of 166 feet that is made up of brown to green clay shale containing thin beds and lenses of sandstone (Hendricks, 1947, sheet 1). The green shales and rounded-frosted-pitted quartz grains in the sandstone of this area are like those of the Simpson group, but the black shales do not occur in any Simpson formations of the Arbuckle Mountains.

The Bromide formation at the top of the Simpson group is one of the most fossiliferous stratigraphic units of the Arbuckle province. It consists of light gray limestone, green shale, and quartzose sandstone

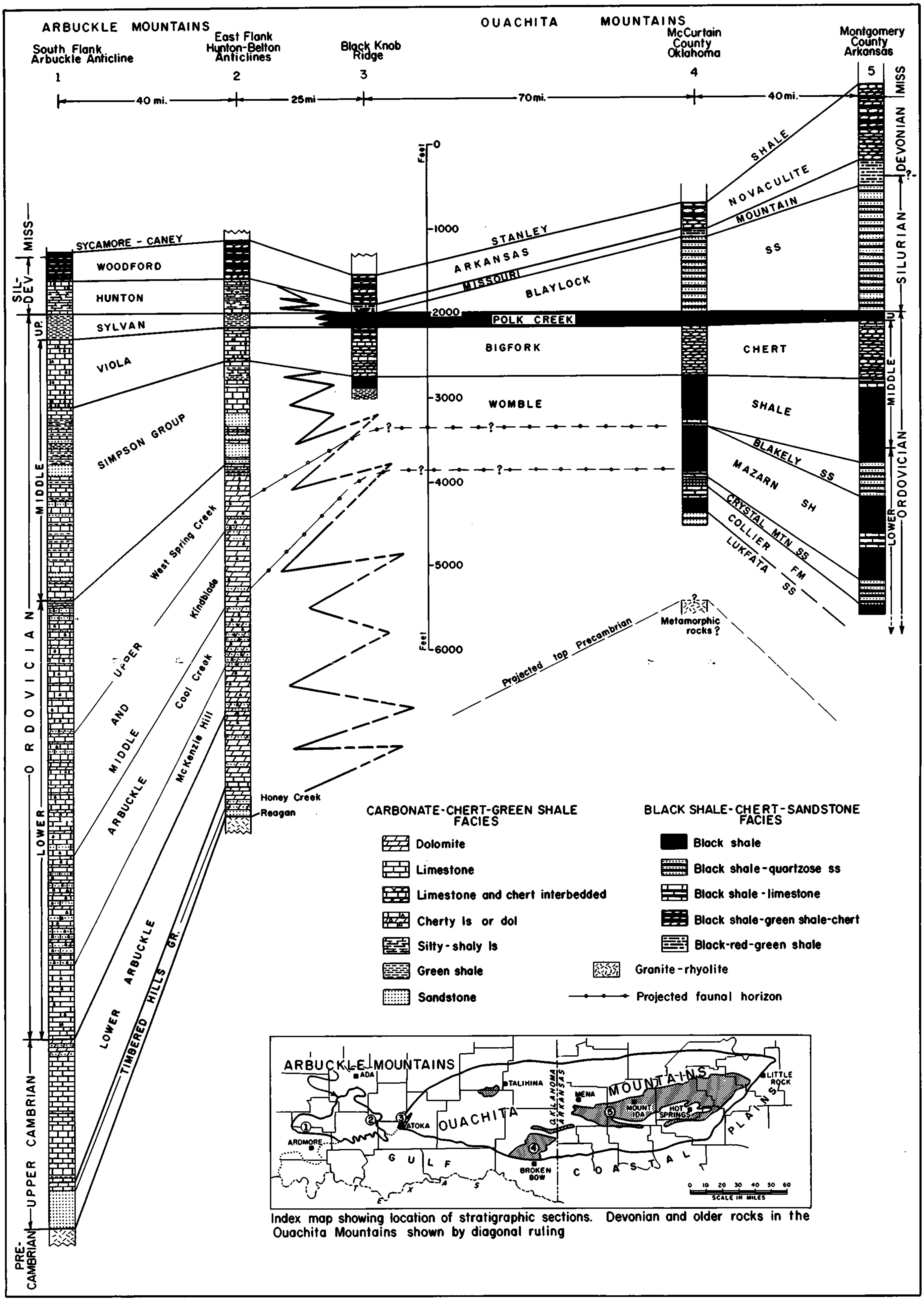

Figure 1. Correlation and facies of pre-Stanley rocks in Ouachita-Arbuckle Mountain regions

300-450 feet thick, and contains an especially prolific brachiopod fauna. Of all the excellent exposures of the Bromide throughout the Arbuckle province, graptolites occurr at only one locality, Rock Crossing in the Criner Hills, where four species were found in the upper 25 feet of the formation. They are *Diplograptus maxwelli, Dicellograptus gurleyi,* and two species of *Dictyonema* (Decker, 1943, pp. 1388-92). The first two species occur also in the Viola limestone. The genus *Dictyonema* has not been recorded from the Viola, but was identified by Ulrich in the Womble at Crystal Springs, Arkansas (Miser and Purdue, 1929, p. 34).

Decker made an exceptionally strong point of the occurrence of *Diplograptus maxwelli* and *Dicellograptus gurleyi* both in the lower Viola and upper Bromide, and chiefly on this basis he correlated all the Bromide with the Trenton (Decker, 1952, p. 135 ff). This correlation is in disagreement with the views of other writers. The exhaustive study by Cooper of Chayzan and related brachiopods shows a faunal discontinuity between Viola and Bromide strata, which is expectable from the physical relations cited above, and it gives a classification of the Bromide as pre-Trenton and post-Chazyan, close in age to what earlier geologists called Black River (Cooper, 1956, p. 123, chart 1).

From the sharply contrasting nature of the Bromide and Womble faunas, great difficulties can be expected in an attempted correlation between them. The graptolite-bearing shales of the Womble do not contain the brachiopods of the Bromide, and there are not enough graptolites in the Bromide to establish a faunal tie. The best approach to date is that of Harlton (1953, p. 780), who states that the conodonts and ostracodes of the Womble at Black Knob Ridge are characteristic Black River or Bromide types. Harlton correlated the upper Womble with the Bromide formation, and this view is accepted by the present writer.

Ouachita equivalents of the pre-Bromide formations of the Simpson group have not been established through faunal control. The Tulip Creek, McLish, and Oil Creek formations make up two-thirds of the Simpson group in the Arbuckle Mountains, and their fossiliferous limestones and shales have yielded a brachiopod fauna of early Middle Ordovician age (Cooper, 1956, chart 1). Graptolites have not been found in this sequence, and thus there is no direct means of correlation with the graptolite shales of the middle Womble. The exhaustive work on ostracodes by Harris (1957) has established well-marked zones of Chazyan and Black River age for all formations of the Simpson group; and if these ostracode zones can be found in the Womble, a satisfactory correlation probabaly can be made.

The discovery of a Lower Ordovician graptolite fauna at one locality near the base of the Womble shale in Arkansas (Miser and Purdue, 1929, p. 33) has considerable value in offering a possible correlation, for the Simpson group is considered to be entirely of post-Lower Ordovician or Canadian age. The position of early Middle Ordovician rocks thus would be middle Womble, which presumably includes equivalents of the Tulip Creek, McLish, Oil Creek, and probably Joins formations.

Upper Arbuckle and lower Womble-Blakely-Mazarn. Early Ordovician strata of the Arbuckle-Ouachita provinces are exposed in widely separated areas, and lithologically they are the most unlike of all the pre-Stanley formations. The section of massive carbonate rocks 5,200 feet thick, that makes up the Lower Ordovician part of the Arbuckle group, is completely unlike the corresponding section of black shales and sandstones of the Ouachita Mountains. Despite the lithologic dissimilarity, the assemblages of fossils are useful for making general correlations.

The very thick Arbuckle group of the Arbuckle Mountains as shown in figure 1 is divided into three roughly equal divisions—upper, middle, and lower. The upper division is discussed in this section. It embraces approximately the upper half of Early Ordovician time, and consists of the West Spring Creek and Kindblade formations (Ham, 1955). Each is composed of limestone and dolomite of shallow-water marine origin. The deposits are fossiliferous, containing brachiopods and gastropods at many horizons, as well as a few restricted zones of trilobites, cephalopods, sponges, and graptolites. In combined thickness the two formations range from 3,000 feet in the southwestern part of the Arbuckle Mountains to 1,700 feet in the eastern part, changing eastward from limestone into dolomite. The sponge *Archaeoscyphia* and the brachiopod *Tritoechia* characterize the lower part of the sequence, and the brachiopods *Pomatotrema, Syntrophopsis, Polytoechia,* and *Diparelasma,* together with two species of *Didymograptus,* characterize the upper part. Horn-shaped opercula of the gastropod genus *Ceratopea* are restricted to the Kindblade and West Spring Creek formations, in which they occur from bottom to top in six well-defined zones (Yochelson and Bridge, 1957). None of these fossils occurs in the Ouachita facies, except *Didymograptus.*

The upper division of the Arbuckle group is here considered to be equivalent to the lower part of the Womble, all the Blakely sandstone, and all the Mazarn shale, as the available faunal evidence indicates for these beds a middle and late Early Ordovician age. The critical information regarding these strata is in Arkansas, where the Womble and Mazarn are chiefly black shale units each about 1,000 feet thick, separated in the central part of the outcrop region by the Blakely sandstone, which has a maximum thickness of 400 feet and consists of sandstone interbedded with black shale in the ratio of 1:3 (Miser and Purdue, 1929, p. 25-33). Each of the three formations contains a graptolite fauna of Canadian or Beekmantown age. The faunal lists of E. O. Ulrich, cited in Miser and Purdue, have been reviewed by W. B. N. Berry and put in terms of more detailed modern knowledge about stratigraphic sequence and age.

In the correlation of this sequence with a part of the Arbuckle group, the upper age limit is established by a collection of graptolites from beds near the base of the Womble shale in the Hot Springs district, the fauna of nine species being correlated with that of a part of the Beekmantown of New York, and thus of Early Ordovician age (Miser and Purdue, 1929, p. 33). In the Ouachita province this is the highest known occurrence of Lower Ordovician fossils, and it serves to correlate the lowest part of the Womble with the upper part of the West Spring Creek formation of the Arbuckle Mountains.

The next lower faunal control consists of graptolites found in shale near the middle of the Blakely sandstone in Blakely Mountain, in the Hot Springs district. The collection of 23 species is characterized by the genera *Didymograptus, Phyllograptus, Tetragraptus,* and *Glossograptus* (Miser and Purdue, 1929, pp. 30-31), and the species list according to Berry indicates Late Canadian age. In terms of Arbuckle rocks, this horizon probably is represented in the lower half of the West Spring Creek formation.

The most significant graptolite fauna, and the lowest fossil zone found thus far in the Ouachita Mountains, is from the lower part of the Mazarn shale. It was collected at a locality two miles northeast of Womble, Arkansas, and contains twelve species of graptolites in the genera *Tetragraptus* and *Didymograptus* (Miser and Purdue, 1929, pp. 27-28). One of the species is *Tetragraptus fruticosus,* which with the associated forms definitely marks a well-developed Middle Canadian zone 250 feet thick in the Marathon limestone, just above the Monument Springs dolomite, in the Marathon region of southwest Texas (Berry, personal communication, 1955). Although this *Tetragraptus* fauna has never been found in the Arbuckle limestone, two fossils from the Monument Springs dolomite in Texas are so well known stratigraphically in the Middle Canadian part of the Arbuckle group that a correlation can be made with considerable assurance. A sponge identified either as *Calathium* or *Archaeoscyphia,* and the brachiopod *Diaphelasma,* occur in the Monument Springs (Bridge, in Sellards et al., 1932, p. 234; and Cloud and Barnes, 1948, p. 66). In the Arbuckle and Wichita Mountains, *Diaphelasma* occurs only in the upper third of the Cool Creek formation, and *Archaeoscyphia* is restricted to the upper part of the Cool Creek and lower third of the Kindblade. From these occurrences it is clear that the Monument Springs dolomite member of the Marathon limestone is equivalent to beds in the upper Cool Creek and lower Kindblade of Oklahoma, and that the *Tetragraptus fruticosus* fauna of the Mazarn and Marathon formations lies stratigraphically in the middle part of the Kindblade formation. Thus the lower part of the Mazarn shale is equivalent to strata just above the middle of the Early Ordovician part of the Arbuckle limestone.

The Blakely sandstone disappears westward in Arkansas and likewise is absent in McCurtain County. In the same areas the Mazarn also becomes thinner, ranging from about 1,000 feet in Arkansas (Miser and Purdue, 1929, p. 26) to about 600 feet in McCurtain County (Pitt, 1955, p. 23).

Older strata. In the Arbuckle and Wichita Mountains, the pre-Kindblade stratigraphic section is mostly fossiliferous and is well exposed down to igneous basement rocks. The section is divided into middle Arbuckle strata, comprising the Cool Creek and McKenzie Hill limestones and dolomites, of Early Canadian age; lower Arbuckle limestones and dolomites of Late Cambrian age; and the Timbered Hills group, also of Late Cambrian age, made up of the Reagan sandstone overlain by the Honey Creek formation. In present knowledge none of these units can be correlated with certainty into the Ouachita province, for there the sandstones, black shales, and thin limestones are unfossiliferous.

Below the Mazarn is the Crystal Mountain sandstone, about 300 feet thick in western Arkansas (Pitt, 1958, personal communication) and not more than 100 feet thick in McCurtain County (Pitt, 1955, p. 21). A thickness of 850 feet has been reported for the formation in Arkansas by Miser and Purdue (1929, p. 24). It is composed mostly of fine-grained and medium-grained sandstone, cemented either by silica or by calcium carbonate, and is interbedded with thin layers of black shale. A basal conglomerate 5-10 feet thick, made up of limestone and chert pebbles in a calcareous sandstone matrix, occurs both in Arkansas and in McCurtain County.

Pitt (1955, p. 18) has compared the Crystal Mountain sandstone ". . . with the McLish sandstone of the Simpson group because both are pure quartz sandstone and both appear to be in about the same stratigraphic position." Evidence from fossils as cited above does not support this comparison, but indicates instead that the Crystal Mountain formation is pre-Womble and pre-middle Canadian in age, in conformance with the opinion of Miser and Purdue (1929, p. 25). As the *Tetragraptus fruticosus* fauna is in the lower part of the Mazarn, just above the Crystal Mountain, and as the *T. fruticosus* zone equivalent probably lies in the middle Kindblade, it follows that the Crystal Mountain equivalent is Lower Kindblade or Cool Creek, low in the middle Canadian part of Early Ordovician time.

Below the Crystal Mountain sandstone is the Collier formation, made up principally of black shale and fine-grained dark limestone. This is the oldest formation exposed in Arkansas. According to Miser and Purdue (1929, p. 23), "The thickness that is exposed in the Caddo Gap quadrangle is 200 feet, but much more, probably several hundred feet, is exposed in the Mount Ida quadrangle, on the north."

In McCurtain County the thickness of the Collier is about 300 feet, divided into an upper limestone member 50-150 feet thick, consisting of silty fine-grained bluish-gray limestone interbedded with thin layers of sandstone and black shale, and a lower shale member 180 feet thick. These figures and a detailed measured section of the limestone member are given by Pitt (1955, p. 15-18). It is the writer's observation that some of the carbonate beds in the Collier are composed of dolomite rather than limestone, and that the rocks of this sequence begin to approach the normal lithology of the Arbuckle group, except that the black shale interbeds and the high silt content of the carbonate rocks are lacking in the Arbuckle province.

In the absence of fossils, the correlation of the Collier can only be surmised. A Cambrian age was suggested by Miser and Purdue (1925, p. 25), but the writer believes that the formation is Early Ordovician, probably equivalent to the lower part of the Cool Creek formation of the Arbuckle group.

According to the account by Pitt (1955, p. 13-15), the oldest formation exposed in the Ouachita Mountains is the Lukfata sandstone. So far as now known, it crops out only in central McCurtain County, where it lies under the Collier shale and has an exposed thickness of 150 feet. The formation consists mostly of black fissile shale and thin-bedded limestone in the lower part, and of fine-grained sandstone interbedded with black and green shale in the upper part. No fossils have been found in it, but the writer believes on the basis of stratigraphic position that the Lukfata sandstone is near the base of the Lower Ordovician, probably correlating with a part of the McKenzie Hill formation of the Arbuckle Mountains.

AN INTERPRETATION OF DEPTH TO PRECAMBRIAN IN MCCURTAIN COUNTY

Under the stratigraphic concepts outlined above, the view has been expressed that even the oldest rocks—those of the Collier and Lukfata formations—are of Early Ordovician age and are probably to be correlated with the middle division or early Canadian part of the Arbuckle group. It is further shown that the base of the Womble is approximately equivalent to the top of the Arbuckle group. With the excellent exposures in the Arbuckle Mountains available for thickness comparisons, it is possible to extrapolate the top of the Precambrian from the Arbuckle province into the Ouachita province at the outcrop locality of the Lukfata sandstone in McCurtain County. The extrapolation can be only approximate, and it is based further on the assumption that (a) no major unconformities shorten the section beneath the Lukfata, and (b) the unexposed rocks have essentially the same sedimentation rates as the exposed rocks.

As deduced from the stratigraphic occurrence of faunal zones of Early Ordovician age, the base of the Womble shale is approximately equivalent to the top of the West Spring Creek formation, and the base of the Mazarn shale is approximately equivalent to the middle Kindblade. The thickness for this dated interval of the Arbuckle limestone, in the eastern part of the Arbuckle Mountains, is about 1,500 feet, and the corresponding interval in McCurtain County is about 600 feet. The thickness ratio is 2½:1. In the eastern Arbuckles the remaining section down to the top of the Precambrian has a thickness of 2,500 feet. To extrapolate from this thickness, the top of the Precambrian in McCurtain County would be 1,000 feet stratigraphically below the base of the Mazarn. A section of 600-foot thickness already is exposed in the Collier and Lukfata formations, leaving under this concept an unexposed thickness of only 400 feet. Presumably these concealed rocks would be entirely of Late Cambrian age.

Approached from a different viewpoint, the extrapolated unexposed thickness has the same order of magnitude. If the Lukfata sandstone is at or near the base of the Lower Ordovician, as suggested above, the 1,200-foot thickness of Cambrian rocks in the eastern part of the Arbuckles can be projected in pre-Lukfata terms; and at the ratio of 2½:1 the estimated depth to Precambrian beneath the Lukfata in McCurtain County is about 500 feet.

Some support for the thickness ratios used above is given by the thickness of all Ordovician rocks in the two areas, the ratio being 4,800:2,500 or about 2:1. This difference would not have material effect on the extrapolations. A further complication is the knowledge that the Precambrian surface is highly irregular in some parts of the Arbuckle Mountains, having a known relief of about 950 feet (Ham, 1949, p. 47). Some allowance must be made for such irregularity, and in figure 1 the pre-Lukfata thickness is shown as approximately 1,000 feet.

The writer knows of no basis for assuming that the basement rocks are necessarily granites. Granites and rhyolitic lavas of Precambrian age crop out in the Arbuckle Mountains; but an elongate tract of Precambrian schists, quartzite, metagraywacke, and meta-arkose is known in subsurface along Red River westward from Love County (Flawn, 1956, plate I). This tract may extend eastward into the Ouachita province, and, if the basement in McCurtain County consists of layered metamorphic rocks or layered volcanic rocks, gravity and seismic readings in that area would be difficult to interpret.

SUMMARY AND CONCLUSIONS

Stratigraphic correlations and regional interpretations of pre-Stanley rocks of the Arbuckle-Ouachita provinces have been advanced remarkably in the half-century during which these regions have been investigated. In perspective view, it appears reasonable that there are no major differences in age or in lithology during Viola-Bigfork, Sylvan-Polk Creek, and Woodford-Arkansas novaculite times; and that within these time periods, entirely similar sediments were deposited in open seaways that connected the Arbuckle and Ouachita provinces. Moreover, it is equally reasonable that considerably different sediments were being deposited simultaneously in the two provinces, but at different rates, first during Lower and early Middle Ordovician time and later during Silurian and Early Devonian time. At such times the respective provinces were (a) either widely separated, the change in facies between them taking place gradually, in which case large-scale thrusting is called for, or (b) the sediments grade into each other within a short distance, the facies change being possibly aided by a barrier of unknown character and position, in which case thrusting is not needed.

From field occurrences alone it does not appear possible to solve this problem, for there are insufficient exposures of beds in the critical frontal belt where the Arbuckle and Ouachita facies are closest. Available for contrast in outcrops of Black Knob Ridge are only the Missouri Mountain shale and the upper part of the Womble formation. If the lower Womble and the Mazarn of that area can be shown by drilling to be dominantly black shales, it would appear unreasonable to the writer that these strata could grade so quickly westward into the Arbuckle facies, and the concept of thrusting should be invoked. If instead the Womble and Mazarn were found to be interfingering or interbedded green shales, dolomites, and limestones, then a gradation into Arbuckle facies will have been demonstrated. A test probably less than 1,000 feet deep, drilled on the Womble outcrop just off Oklahoma Highway 3, one mile southeast of Atoka, would have a fair chance to solve this fascinating enigma.

Another concept that is being clarified is the unequal geosynclinal behavior of pre-Stanley rocks in the Ouachitas compared with those in the Arbuckles, the sediments in the two areas reflecting unequal rates of accumulation during specified times. In pre-Silurian time, by far the thicker section was laid down in the Arbuckle province, where the Ordovician-Upper Cambrian section of predominantly carbonate rocks reaches a near-geosynclinal thickness of 10,800 feet. The thickest corresponding section in the Ouachitas is mostly clastics and probably is about 5,000 feet—a figure that is only an approximation because the lowest beds, which are not exposed, must be estimated by extrapolation. In contrast, the section of Silurian and Devonian rocks has a maximum thickness of 2,700 feet in the Arkansas part of the Ouachitas, compared with a maximum thickness of 900 feet in the Arbuckles. Thus the end of Polk Creek-Sylvan time at the close of the Ordovician marks a time boundary below which maximum sinking was in the Arbuckle province, and above which maximum sinking was in the Ouachita province.

The difference in subsidence behavior for the two regions also is shown through thicknesses given by rock systems (fig.1). In Arkansas the sediment thicknesses are approximately 3,600 feet for Ordovician time, 1,800 for Silurian, and 900 for Devonian, and the Ordovician : Silurian : Devonian thickness ratio is 4:2:1. These data bear no similarity to those in the west, for in the thickest corresponding section of the Arbuckle Mountains the Ordovician:Silurian:Devonian thicknesses are 8,500:350:800 feet, in a ratio of approximately 25:1:2.

The Arbuckle province thus consists almost exclusively of an Ordovician geosynclinal tract. The sea floor of this province during Ordovician time was sinking so rapidly that it was literally falling, whereas in the Silurian and Devonian it was by comparison just barely sinking, and received thin layers of sediments. The dissimilar Ouachita province sank progressively and at a reasonably constant rate not only in Ordovician time but in Silurian and Devonian time as well.

Another regional feature worthy of discussion is that the pre-Stanley rocks thin markedly eastward in the Arbuckles and markedly westward in the Ouachitas, as though they were merging toward a common shelf between them (fig. 1). In the Ouachita province the thinning is due partly to a slower rate of subsidence, but in considerable part it is also due to the loss of clastic sediments away from the source area, which lay presumably in Llanoria to the southeast. Both the Blaylock and Blakely sandstones follow this pattern, as they are thickest in the east and disappear westward. The kind of sediment deposited at any given time, however, does not change materially in character from west to east, as near as can be determined from outcrop control.

The Arbuckle province on the other hand is characterized, during Cambrian-Ordovician time, by a modest change in lithology from limestones in the west to dolomites in the east, and by an accompanying change in thickness from about 7,500 feet to 4,200 feet. The Simpson group and Viola limestone similarly thin eastward, but the only pronounced change in lithology is the occurrence in the McLish formation of the algal "birdseye" limestone instead of bioclastic calcarenite (Ham, 1954; 1955, p. 29-30). The Woodford shale does not differ significantly in thickness or character within the Arbuckle province, but the thickness of formations in the Hunton group does show a considerable range, primarily as the result of five intra-group unconformities in addition to a pronounced unconformity at the base of the overlying Woodford (Amsden, 1957, p. 6). The essential point is that pre-Hunton strata make up approximately 87 percent of the pre-Stanley stratigraphic section in the eastern part of the Arbuckles, and that these strata change slightly in lithology while undergoing a thickness loss of nearly 50 percent, evidently by less deposition on a more slowly subsiding shelf. It is not known whether this dominantly carbonate facies of the eastern Arbuckles actually abuts against dissimilar rocks in the Ouachitas near Atoka, as most of the equivalent rocks are not exposed.

Finally, the term "Ouachita geosyncline" should be used in reference to the Stanley, Jackfork, and Atoka sediments of the Ouachita province, as this sequence according to Hendricks (1947, sheet 1) has the geosynclinal thickness of about 28,000 feet and was deposited during the relatively short span of Mississippian and Early Pennsylvanian time. The term "Ouachita geosyncline" should *not* be applied to the pre-Stanley rocks of the Ouachita province, because they are not geosynclinal in thickness, even in their thickest exposures, but were spread as a westward-tapering blanket on a moderately subsiding shelf. The general increase in thickness toward the east suggests that the Ordovician, Silurian, and Devonian sediments are expanding toward a geosynslinal site, which probably had the form of a linear trough in the foredeep of Llanoria. The sediments there presumably were deposited mainly as conglomerates, coarse sandstone, and shale with a thickness magnitude of perhaps 20,000 feet. This hypothetical trough would constitute a pre-Stanley Ouachita geosyncline, of which the exposed Devonian and older black shales and associated sediments represent deposits on a fringing shelf. Collapse, metamorphism, and uplift of this early Paleozoic geosynclinal tract is seen as the source of sediments needed for the filling of the newly developing late Paleozoic geosyncline. Obviously the keels of the two geosynclines lie in different geographic positions, the earlier being now deeply buried under a cover of Cretaceous and younger sediments in northen Louisiana and northeast Texas, and the younger coinciding approximately with the present position of the Ouachita Mountains.

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NEW *Paradelocrinus* FROM OKLAHOMA

HARRELL L. STRIMPLE

A group of crinoids assigned to the genus *Paradelocrinus* differs from the typical forms in lacking a well-defined basal concavity. The most prolific species of this specialized group is *Paradelocrinus subplanus* Moore and Plummer, from the Desmoinesian of Oklahoma and Texas. It is a highly variable species as represented in the Oologah limestone formation of northeastern Oklahoma, and some specimens have a mild basal concavity. A new species from the Atokan, described herein as *P. atoka*, new species, has a decided basal concavity. Conversely an older form described as *P. wapanucka*, new species, has no basal concavity other than the sharply impressed area for the reception of the proximal columnal. A new Desmoinesian form is described as *P. johnstonensis*, new species, which also lacks a decided basal concavity. There is in many specimens a tendency for the radial plates to make contact with the infrabasal plates in this specialized group of "flat-bottomed" *Paradelocrinus*, but the same tendency is found in *P. atoka* which species has a concave base.

ERISOCRINIDAE S. A. Miller
Paradelocrinus Moore and Plummer

Paradelocrinus wapanucka Strimple, new species
Plate I, figures 7-9

The dorsal cup is low bowl-shaped. There is no basal concavity other than the sharply impressed area for the reception of the proximal columnal. The infrabasals extend slightly beyond the depressed area. Five basals are rather large plates that curve upward to form part of the lateral walls of the cup. Five radials are wide pentagonal plates. There is no strong curvature of the radials at the summit of the cup. The exact position of the rudimentary anal plate, that is certain to be in the interarticular surfaces of the radials, is not determined. The arm-articulating facets are well preserved. Grooves and pits of the outer ligament areas are well defined as thin, sharply impressed elements. The lateral furrows are prominent, but the most interesting feature to me is the thin but sharply defined intermuscular furrow. It is distinctive under low magnification. The oblique furrows are well defined. There appears to be a mildly irregular, granular surface to the cup, but this might be caused by differential weathering. The columnar scar is round and the lumen appears to be round. Arms are not known.

Measurements in millimeters:

	HOLOTYPE
Width of dorsal cup (maximum)	11.9
Height of cup	5.1
Width of infrabasal circlet	3.7
Length of basal	3.5*
Width of basal	3.5*
Length of radial	4.7*
Width of radial	7.0*
Diameter of columnar scar	2.3

*Measurement taken along surface curvature.

Remarks.—There are two other Morrowan species of the genus known: *P. aequabilis* Moore and Plummer (the genotype species) and *P. dubius* (Mather). Both are from the Brentwood limestone, Bloyd formation, and are readily distinguished from *P. wapanucka* in that they possess a basal concavity. *P. aequabilis* is a slightly smaller and relatively lower species, and *P. dubius* is a larger form having an exaggerated basal concavity.

Occurrence.—Wapanucka limestone formation, Morrowan, Pennsylvanian; near C sec. 8, T. 1 N., R. 7 E., Pontotoc County, Oklahoma.

Holotype.—Collected by Allen Graffham. Paleontological collections, The University of Oklahoma, OU 4331.

Paradelocrinus johnstonensis Strimple, new species

Plate I, figures 4-6, 10-12

The dorsal cup is broad, shallow, bowl-shaped, with a broad gentle basal concavity that is scarcely discernable. There is a sharply impressed area for the reception of the proximal columnal. Five infrabasals extend beyond the impressed area occupied by the proximal columnal. The basal plates are of moderate size and only the outer tips of the plates are visible in the side view of the cup. Five large radials form most of the cup height with their proximal tips participating in the broad basal area. This species does not normally exhibit the tendency for the radials to establish contact with the infrabasals. The upper portions of the radials are curved inward, a characteristic of *Delocrinus* and/or *Endelocrinus,* but not of *Erisocrinus.* The contour of the cup is circular as viewed from above or below. The articular facets of the radials are subhorizontal and they are rather distinctive. There is a broad prominent outer ligament furrow and a sharp outer ligament ridge. The ligament pit is rather large and is partly occupied by an "extra" ridge that is strongly marked by denticles. The transverse ridge is also strongly marked by denticles. Lateral furrows are well defined and the intermuscular notch is shallow. The intermuscular furrow and central pit are prominent. Adsutural slopes are low and widen toward the interior of the cup. A broad notch for the anal plate is on the inner edge of the facets in posterior position. All cup plates are smooth.

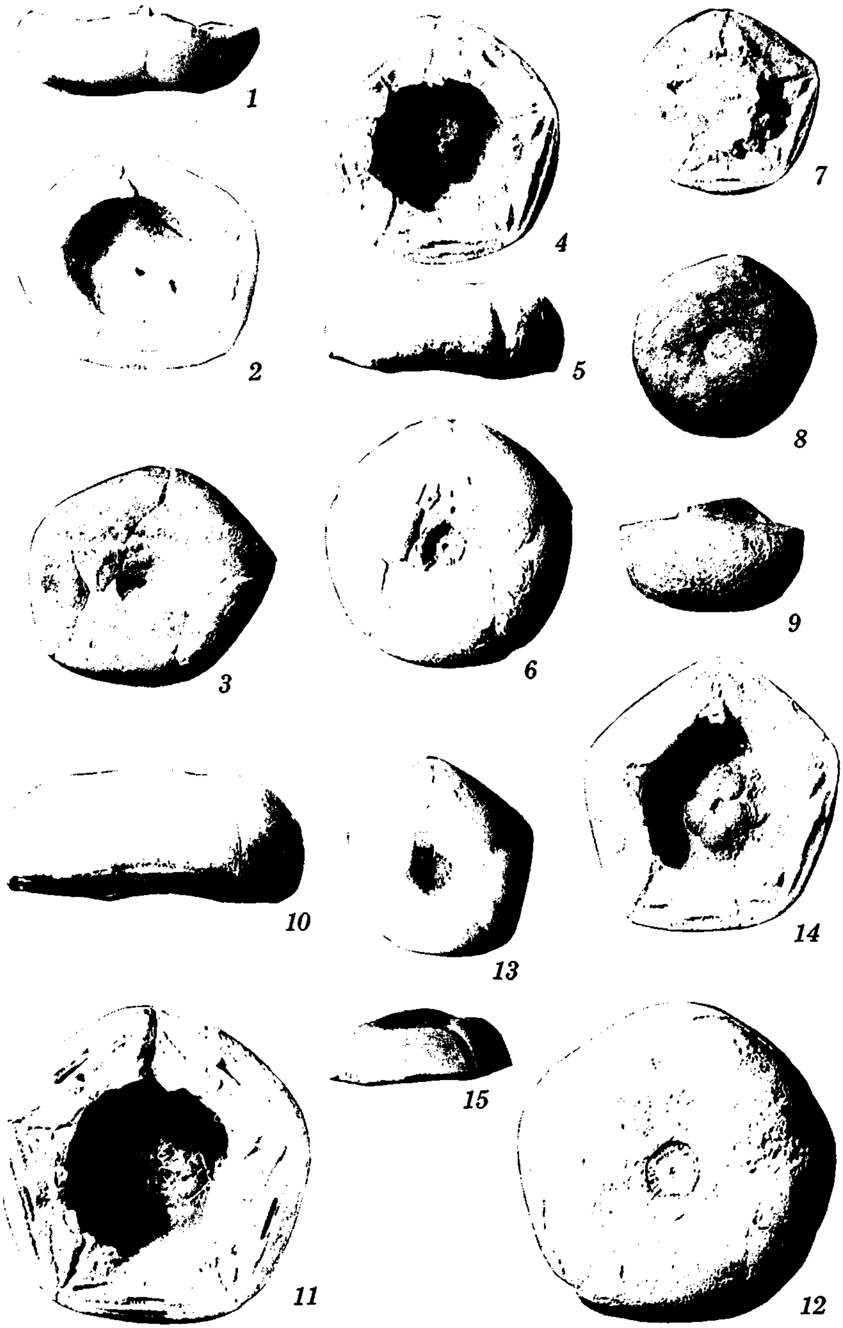
Measurements in millimeters:

	HOLOTYPE
Width of cup (maximum)	21.7
Height of cup	7.7
Length of basal	5.8*
Width of basal	6.4*

Explanation of Plate I

Figures 1-3.	Paradelocrinus atoka **Strimple, new species, paratype OU 3961, viewed from posterior, above, and below, ca. x2.**
Figures 4-6.	Paradelocrinus johnstonensis **Strimple, new species, paratype OU 3958, viewed from above, anterior, and below, ca. x2.**
Figures 7-9.	Paradelocrinus wapanucka **Strimple, new species, holotype OU 4331, viewed from above, below, and side, ca. x2.**
Figures 10-12.	Paradelocrinus johnstonensis **Strimple, new species, holotype OU 3959, viewed from anterior, above, and below, ca. x2.**
Figures 13-15.	Paradelocrinus atoka **Strimple, new species, holotype OU 4332, viewed from below (x2), above (x3), and anterior (x2).**

PLATE I



Length of radial	11.3*
Width of radial	13.1*
Width of infrabasal circlet	6.0
Width of proximal columnal	4.0

*Measurement taken along surface curvature.

Remarks.—This species is closer to *P. regulatus* Strimple than to other described forms. It differs in that the former species has unusually short sutures (or no sutures) between basal plates, and the dorsal cup is more compact than in *P. johnstonensis*.

Occurrence.—Pumpkin Creek limestone, Dornick Hills formation, Desmoinesian, Pennsylvanian; NE¼ sec. 31, T. 4 S., R. 4 E., Johnston County, Oklahoma.

Types.— Holotype and figured paratypes are deposited in the paleontological collections, The University of Oklahoma, numbers OU 3959 and 3958. Two paratypes are to be deposited in the Springer Collection, U. S. National Museum, Washington, D. C.

Paradelocrinus atoka Strimple, new species

Plate I, figures 1-3, 13-15

The dorsal cup is shallow, bowl-shaped, with a mildly pentagonal outline as viewed from above or below. There is a broad basal concavity with the infrabasals and most of the five basals confined to the cavity. The proximal portions of the radials also participate in the basal area. There is a strong tendency toward elimination of the suture between basal plates, a feature atypical of the genus, but observed in several species of Desmoinesian age. The most prominent element of the cup is the large radial plate. The articulating facets are subhorizontal. Outer ligament areas and features are well defined. The intermuscular area is sharply depressed. Lateral furrows are relatively large and muscular areas are relatively small. The intermuscular notch is poorly defined and the furrow is short. The single anal plate is small and rudimentary, resting in a notch between articular facets in the posterior position.

Measurements in millimeters:

	HOLOTYPE
Width of dorsal cup (maximum)	12.7
Height of cup	3.7
Width of columnar scar	2.1
Width of IBB circlet	3.9
Length of basal	2.4*
Width of basal	3.7*
Length of radial	5.7*
Width of radial	7.9*

*Measurement taken along surface curvature.

The column is round and the axial canal appears to be round. Arms that have been found associated with the cups, or in close proximity, have the appearance of arms associated with *Erisocrinus*.

Remarks.—The unusually shallow dorsal cup, with broad, well-defined basal concavity, is destinctive of *P. atoka*. The species *P. disculus* Strimple is also a shallow form, but it does not have a basal concavity.

Occurrence.—The holotype is from the "Griley" limestone, Atokan, Pennsylvanian; near C N½ sec. 28, T. 1 N., R. 8 E., Coal County, Oklahoma. The figured paratype is from a shale zone slightly higher than the "Griley" limestone in SW¼ sec. 23, T. 1 N., R. 8 E. (original label shows SW corner sec. 14) about 6 miles south of Tupelo, Coal County, Oklahoma.

Types.—Holotype, collected by Mr. Allen Graffham, in paleontological collections, The University of Oklahoma, OU 4332; paratype, collected by Mr. Treadwell, in paleontological collections, The University of Oklahoma, OU 3961; paratype, collected by H. L. Strimple, in paleontological collections, The University of Oklahoma, OU 3962; paratype, collected by H. L. Strimple, to be deposited in the Springer Collection, U. S. National Museum, Washington, D. C.

The Type of *Pentremitella*, A Lower Devonian Blastoid from Germany

Robert O. Fay

The type specimen of *Pentremitella osoleae* Lehmann, 1949, from the Hunsrückschiefer (Lower Devonian), Bundenbach, Germany, is on deposit in the Geologisch-Palaeontologisches Institut und Museum der Rhein, Friedrich Wilhelms-Universität, Bonn. I wish to thank Professor Doctor H. K. Erben of that university, for loan of the type specimen.

The specimen is compressed in black fissile argillite, preserved as calcite and pyrite, and is almost unrecognizable for even generic assignment. The brachioles are intact and cover most of the specimen, thus obscuring the deltoids and spiracles. The calyx appears to be rounded obconical in side view, with theca 21 mm long by 8 mm wide, vault 9 mm long, pelvis 12 mm long, and pelvic angle approximately 30 degrees. The basals are obscured but appear to be about 4 mm long, perhaps attached to a stem 16 mm long by 0.5 mm wide. The radials are about 12 mm long by 4 mm wide, with a broad shallow sinus approximately 6 mm long by 1.5 to 2.0 mm wide. The brachioles appear to be normally disposed, each composed of a biserial set of brachiolars.

The specimen is on a thin slab showing both sides. The main part of the specimen is shown on plate I and the reverse side is shown on plate II, figure 2. The brachioles on the left side of the main part are shown enlarged on plate II, figure 1. Plates I and II are on pages 230 and 231.

It is here recommended that the name *Pentremitella* not be applied to other specimens or used in synonymic lists because the critical generic characters are obscured.

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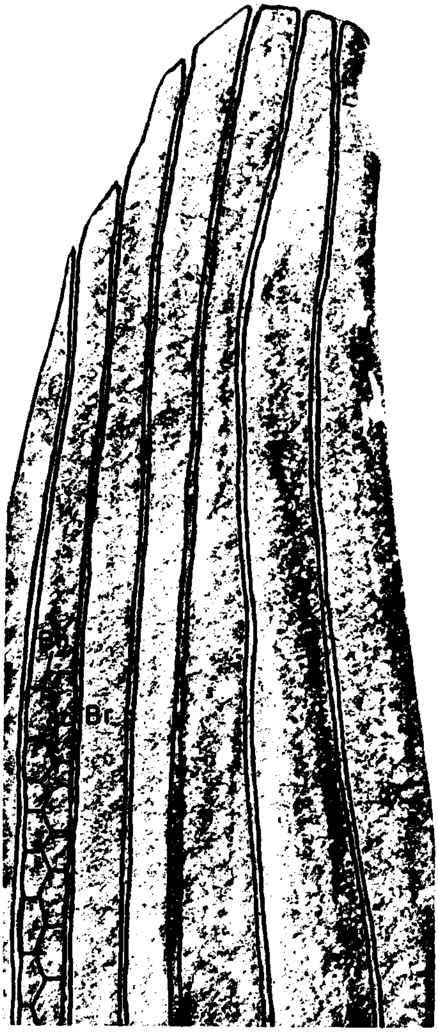
Plate I

Pentremitella osoleae Lehmann, 1949. Side view of holotype showing main part of specimen, x5.7. B—basal plate, R—radial plate.



1

2

Plate II

Pentremitella osoleae **Lehmann, 1949. Holotype, Bonn, Germany.**

Figure 1. Enlarged view of brachioles on left side of main part of specimen, x13.8.

Figure 2. Side view of reverse side of specimen, x5.7.

B—basal plate
Bh—brachiloar plate
Br—brachiole
R—radial plate

Two New Brachiopod Genera from Oklahoma

The new terebratuloid genus *Gacina* was recently erected by Stehli for the new species *G. moorefieldensis,* collected from the Moorefield formation in Oklahoma. The locality is given as NW¼ NW¼ sec. 18, T. 15 N., R. 21 E. The locality is in Cherokee County and is described in Huffman (1958, p. 171) and would seem to be in the Bayou Manard member.

The new genus *Pakistania* is erected on *Dielasma biplex* Waagen, 1882, a species from the Productus limestone of the Salt Range in Pakistan. Stehli assigns *Dielasma schucherti* Beede, 1902, to the genus, refers Beede's figures 1-16 to the species in the new combination *Pakistania schucherti,* and cites the specimens as from the White Horse sandstone of White Horse Spring, Woods County, Oklahoma. The collection is from the Doe Creek sandy limestone member of the Marlow formation in the Whitehorse group (Guadalupean). The reference cited is the Advance Bulletin of Oklahoma Territorial Geological and Natural History Survey, First Biennial Report. All of the other manuscripts and the specimens described were lost in the fire which destroyed the building housing the survey. The citation should read plate 1, figures a-d. Beede later (1907) published an augmented description and further illustration of his *Dielasma schucherti* based upon neotype specimens. The species was divided by Brill in 1940, who left Beede's 1902 plate 1, figures 1a-c and Beede's 1907 plate 5, figures 1b, 1c, 1d, 1f, and 1m in *Dielasma schucherti,* and erected a new genus, *Pseudodielasma,* for Beede's 1907 figures 1, 1a, 1e, 1g-j, with the new specific name *Pseudodielasma perplexa.* Figures 1k and 1l were referred to *Composita.*

The genus *Pakistania* would then seem to be represented by Beede's 1902 *Dielasma schucherti* as based upon the 1907 neotype figured as plate 5, figures 1b-d. Brill refigured the neotype (pl. 10, fig. 3) and figured two hypotypes (pl. 10, figs. 1-2, 4). Brill called attention to the similarity to *D. biplex* Waagen, now placed with *D. schucherti* in *Pakistania.*

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C. C. B.